International Journal of Applied Power Engineering (IJAPE)
Vol. 12, No. 3, September 2023, pp. 247~254
ISSN: 2252-8792, DOI: 10.11591/ijape.v12.i3.pp247-254

Closed-loop control of BLDC motor using Hall effect sensors

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Article Info

Article history:

Received Mar 31, 2023
Revised Apr 27, 2023
Accepted May 7, 2023

Keywords:

BLDC motor
Hall effect sensors
PID controller
Speed
Torque

ABSTRACT

Due to its key advantages of top performance, strong torque, and simple volume, brushless direct current (BLDC) motors are now extensively employed in a variety of industrial sectors, including the automotive industry, robotics, and electrical vehicles. Yet, in some circumstances, it can be challenging to use speed control techniques for specific devices. The major goal of this work is to use a proportional integral derivative (PID) converter to regulate the speed characteristics of BLDC. PID converter is preferred over all other converters because of its straightforward design and straightforward implementation. Using MATLAB simulation results are verified at different reference speed changing conditions, the motor input current and back electromotive force (EMF) values are verified. The speed and torque characteristics are verified during steady and transient state conduction.

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1. INTRODUCTION

The significance of brushless direct current (BLDC) motor drives has gained more in the last decades due to their power quality improvement and their extraordinary performance compared with other drives [1], [2]. Field windings and armature windings are located on the stator and rotor, respectively, in DC motors. Because there are brushes and dust has built up in them, upkeep is more expensive. Due to their tendency to arc, DC motors can only be used in certain hazardous industries [3], [4]. The BLDC motor could be changed to resolve this. Because it is more efficient, requires less money, has a large ratio of torque to weight and is simple to operate at all speeds [5], [6]. The importance of taking into account a large ratio of torque to weight is that it has a long operational life, is silent, and is more effective than others [7]. The BLDC motor can solve the issue of electrical erosion and mechanical friction. Hall sensors are used to determine the motor's position [8]. To achieve a smooth speed operation and torque with a low ripple content, the motor must be controlled]. Electronic commutation of the BLDC motors results in trapezoidal back electromotive force (EMF) signals. The proportional integral derivative (PID) controller adjusts the motor's input voltage continually based on the discrepancy between the intended speed and the true speed. The PID controller's proportional, integral, and derivative gains are adjusted to produce the desired responsiveness and stability [9]. In an open loop, BLDC motor the control technique involves voltage control, pulse width modulation (PWM), and frequency control [10]. The open-loop speed control is more accurate than the closed-loop speed control as external factors like temperature and load variations are included [11]–[15]. The open loop BLDC motor model is used in MATLAB, and the responses are used to study under various circumstances.

2. BRUSHLESS DC MOTOR

Figure 1 shows the permanent magnet rotor (moving component) and stator windings make up a BLDC motor (fixed part). The brushless DC motor is an AC synchronous motor without brushes or commentators [16]–[19]. It has a compact form, noiseless operation, long operation life, and high efficiency, unlike DC motors. Hall effect sensors (H) monitor the coil's position concerning the motor's magnetic field.

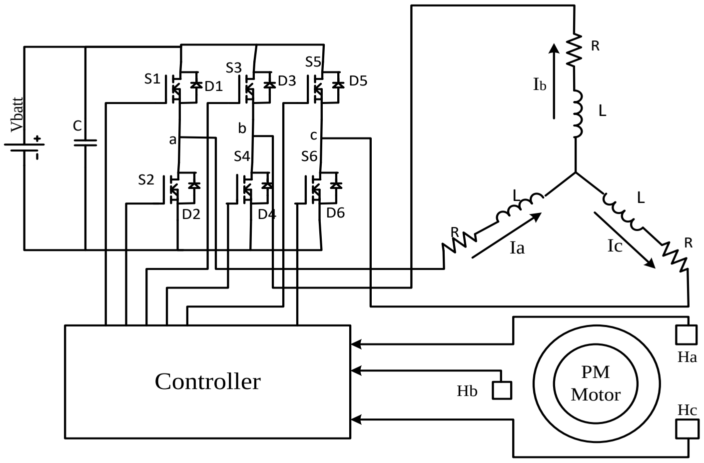


Figure 1. Equivalent circuit of brushless DC motor [4]

A stator is connected in Y in a BLDC motor type, and each phase's resistance and inductance are equal. Losses like those caused by iron cores, eddy currents, and hysteria are disregarded. The BLDC motor's phase voltage formula is displayed as (1).

$$\begin{bmatrix} u_A \\ u_B \\ u_C \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_A \\ i_B \\ i_C \end{bmatrix} + \begin{bmatrix} e_A \\ e_B \\ e_C \end{bmatrix} \quad (1)$$

Figure 2 shows the back EMF waveforms, Hall effect sensor waveforms and current waveforms of the BLDC motor. The wave forms are varied each 60°, the back EMFs are at each instant one positive, one negative and third EMF zero. A brushless DC motor's electromagnetic torque is computed as (2).

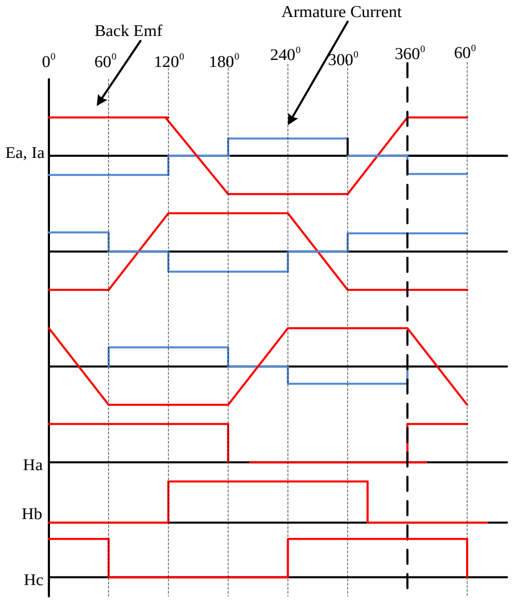


Figure 2. Characteristic waveforms of a BLDC motor [5]

$$T_e = \frac{e_A i_A + e_B i_B + e_C i_C}{\omega_m} \quad (2)$$

Where ω_m is the rotational angular velocity in radians per second and T_e is the electromagnetic torque. To calculate the motion of the BLDC motor:

$$T_e - T_L = \frac{Jd\omega_m}{dt} + B_v \omega_m \quad (3)$$

where, T_L is load torque, J is the moment of inertia of the motor a Bvisthe friction coefficient. The equation for the relationship between the rotor's location and speed is (4).

$$\frac{d\theta}{dt} = \frac{P}{2}\ \omega_m \quad (4)$$

Where P is the number of poles and is the rotor's pole position.

3. CONTROL SCHEME

3.1. Brushless DC motor speed adjustment

Figure 3 shows the most popular method of controlling BLDC motors is by the use of Hall sensors, which serve the dual purposes of position and speed sensors. Nevertheless, its primary flaw is that it collects current speed data, which is displayed as inaccurate [20]–[22]. In this paper, we use pulse width modulation (PWM) for controlling the power to the device. The main advantage of this technique is low power losses while switching the devices. Two loops are shown in the block diagram above, one of which is used to measure the speed of the BLDC motor, and the other of which is used to power a three-phase, six-step inverter. The generated torque must match the driver's desired torque and be in control of the brake and accelerate pedals. Torque control is a need. In the range up to the rated speed, torque remains constant. The BLDC motor can operate at its top speed, but the torque may decrease. Torque control can be mainly used in traction units and electric cars.

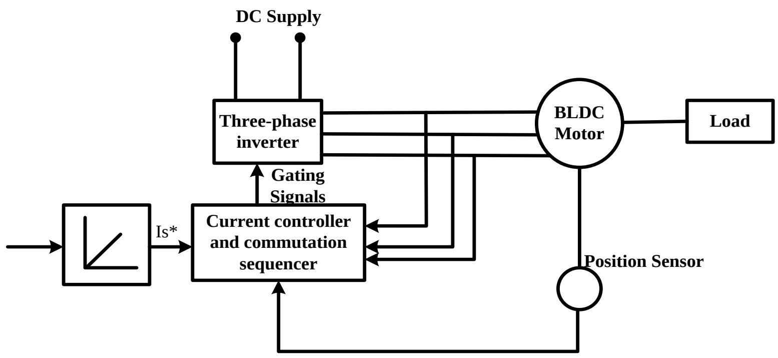


Figure 3. Block chart of the torque control scheme

3.2. PID controller mathematical equations

The motor's speed, torque, and voltage are measured and relayed back as feedback using a PID controller [23]–[25]. The terms proportional (P), integral (I), and derivative (D) make up a PID controller. The controller can shorten the rise time and dampen oscillations.

- The transfer function of the PID controller

$$u(s) = \left[K_p + \frac{K_i}{s} + K_d s\right] E(s) \quad (5)$$

- Controller equation in the time frame

$$u(t) = K_p e(t) + K \int_i^t e\ (t)dt + \ K_d \frac{de}{dt} \quad (6)$$

$$u(t) = K_p \left(e(t) + \frac{K_i}{K_p} \int^t e\ (t)dt + \frac{K_d}{K_p}\frac{de}{dt}\right) \quad (7)$$

$$T_i = \frac{K_p}{K_i} \ and \ T_d = \frac{K_d}{K_p} \quad (8)$$

$$u(t) = K_p\left(e(t) + \frac{1}{T_i}\int^t e(t)dt + T_d\frac{de}{dt}\right) \quad (9)$$

3.3. Commutation logic

A brushless DC engine is an electric motor that requires an electronic commutation system to control its speed and direction. Unlike DC motors BLDC motors do not use brushes to transfer the power instead they use a controller to send electric signals to motor windings to generate a rotating magnetic field. Figure 4 shows the logic gate circuit for switching on the inverter circuit. Figure 4(a) shows the Hall effect signal to EMF signal. Figure 4(b) shows the EMF signal to GATES. The Hall effect sensors are used in the control scheme. The Hall effect sensors are a key role in the BLDC motor circuit.

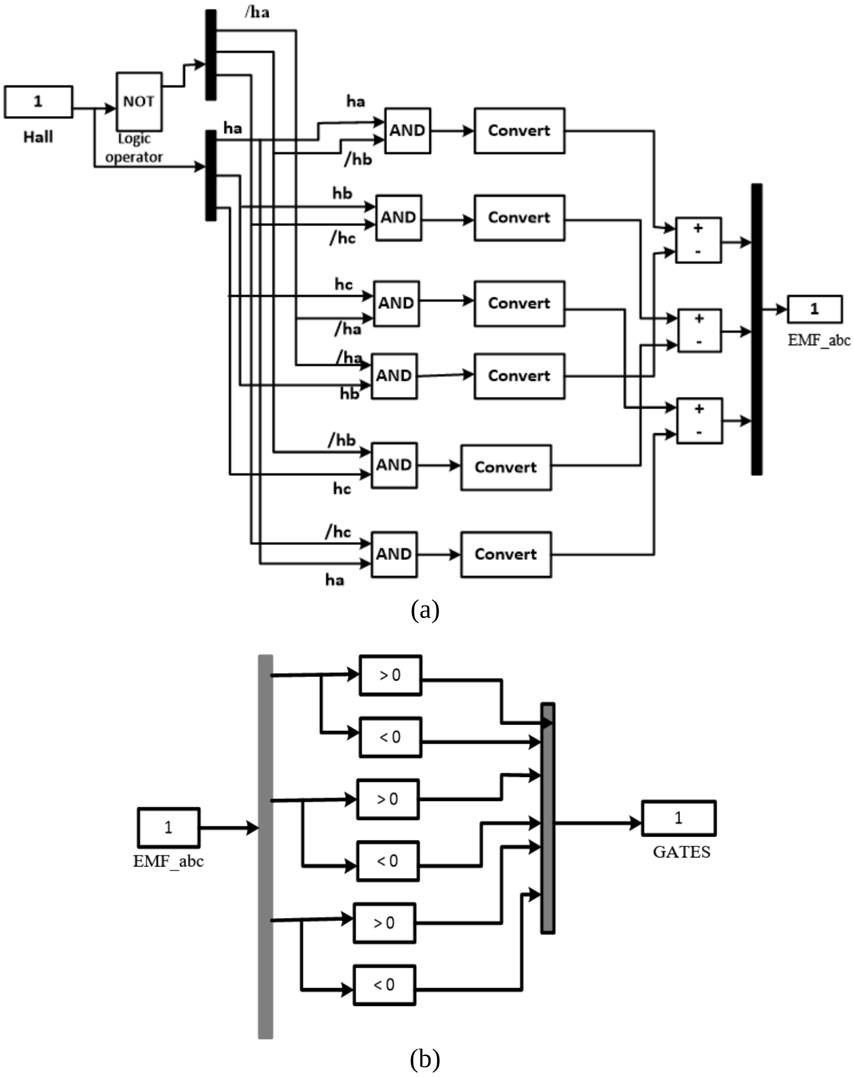


Figure 4. Logic circuit connecting from (a) Hall to EMF and (b) EMF to GATES

4. SIMULATION RESULTS

Figure 5 depicts the output response of stator currents of A, B, and C to time. The maximum amplitude of the waveform is 3 A. Phase B and C are the same as phase A but 120 electrical degrees phase shift to each other. Figure 6 depicts the output response of the back EMFs of the engine. The signal is called a TRAPEZOIDAL SIGNAL. The three-phase stator back EMF magnitudes are shown in the figure. The magnitude is 200 V. The magnitude of voltage is 0 to 0.1 s is a very less and transient state.

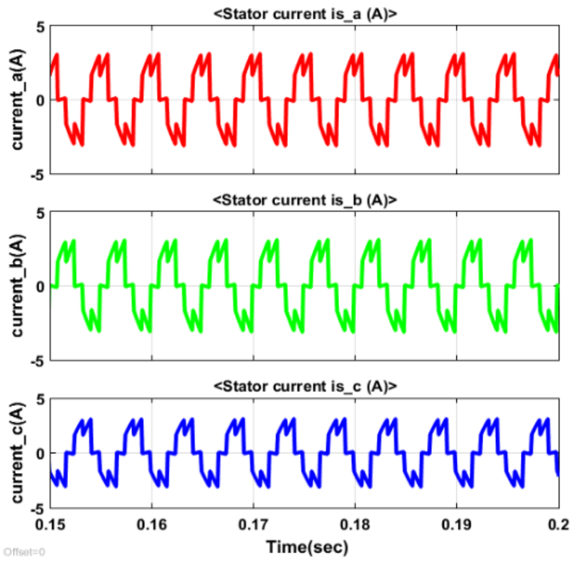


Figure 5. Three-phase stator current characteristics

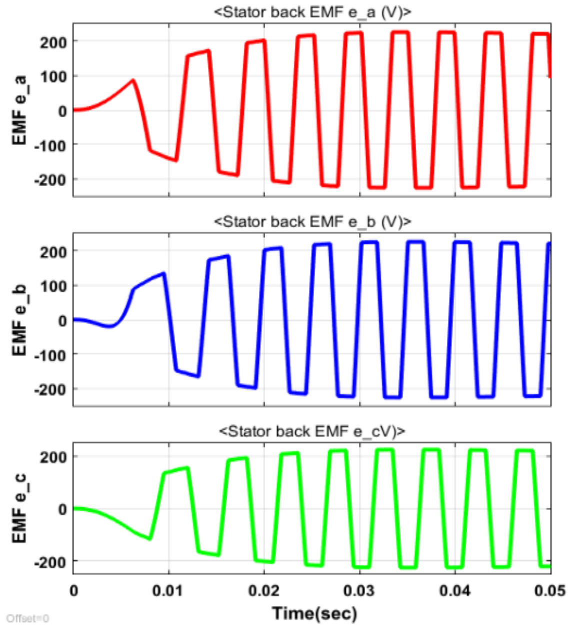


Figure 6. Back EMF characteristics

Figure 7 depicts the output response of the speed-torque characteristics. Here the supply voltage is constant. Speed took 3000 rpm. Here torque is inversely proportional to the speed. Speed is measured in rpm and torque is taken as newton per meter. The motor's rate of spinning depends on the relation between the applied voltage and the loaded torque. Figure 8 depicts the output responses of the Hall effect signals for phases A, B, and C. The signals represent the density of a magnetic field around the device.

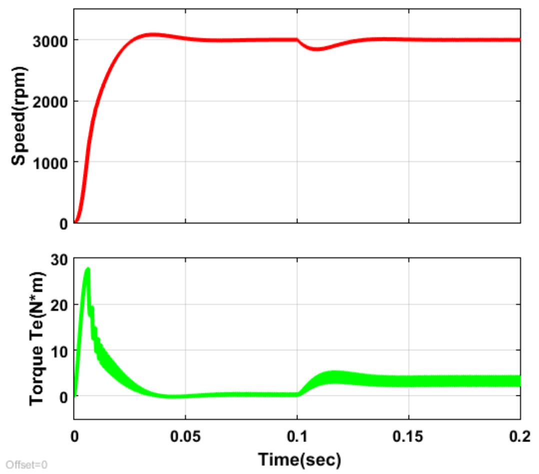


Figure 7. Speed-torque characteristics

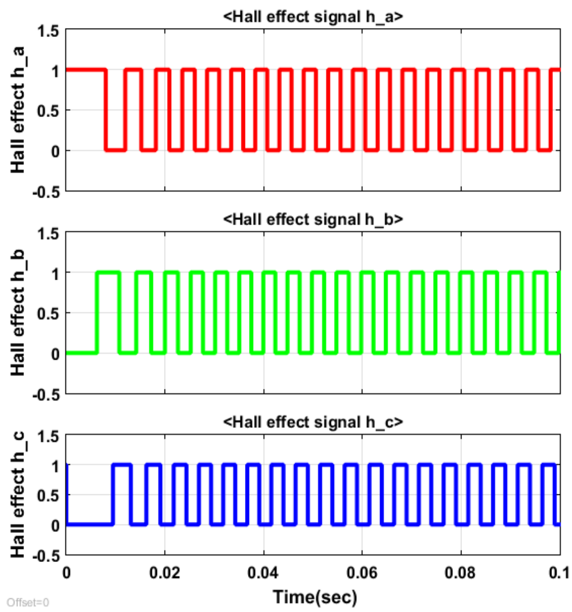
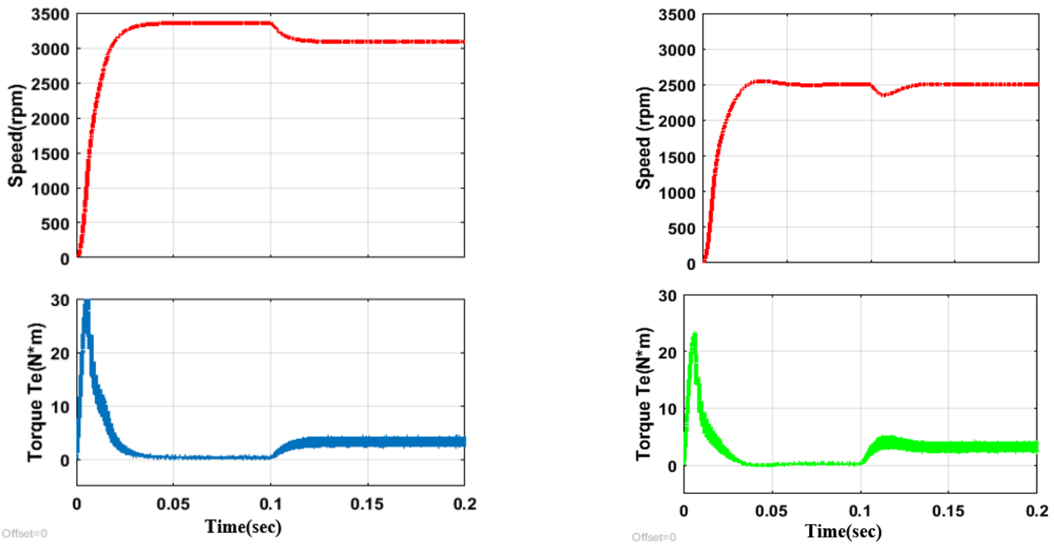


Figure 8. Hall effect signal characteristics

Figure 9 shows the output responses of the motor in two different speed conditions. The Figure 9(a) is taken when the motor speed is 3500 rpm. The Figure 9(b) is taken when the speed is 2500 rpm. From the above speed-torque characteristics we can conclude that the output result doesn't change even if the speed varies.



(a) (b)

Figure 9. Speed-torque characteristics in different speed conditions (a) reference speed 3000 rpm and (b) reference speed 2500 rpm

5. CONCLUSION

This study described how to effectively control the speed of an open loop brushless DC motor. A BLDC engine's pace can be controlled using a PID controller in a variety of applications. Moreover, it offers improved precision and lessens motor wear and tear. The paper's primary goal is to demonstrate how long a motor can operate reliably. MATLAB/SIMULINK software is used to verify the characteristics, including stator current, back EMF, and speed-torque characteristics, which are considered under various speed situations.

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